International Baccalaureate Programme

Physic Extended Essay

"The effect of distance between point light source and target metal to stopping potential"

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Abstract

The research question of the experiment is “In a photoelectric system , what is the effect of distance between tungsten lamp and the metal photoelectric module on the stopping potential of system and how does the effect vary with changing wavelength of light?”. The research question stated with an assumption , “If the distance between the light source and target metal is increased, the stopping potential applied for the photoelectrons decreases.” to check the formula based on photoelectric theory. The reason of this research question came with a curiosity that how can a formula based on a theory can be 100% precise and why miscellenous conditions have no effect on the results? The investigation was started with a pre-experiment to examine the uncertainty value of photoelectric system. The experiment was consisted of evaulating Planck constant which could differ slightly due to the usage of different material. Then the main experiment was occured with the same material and without any difference in controlled variables except the change in distance between light source and target metal to stopping potential of the photoelectric system. To find a result with less uncertainty, five color filters used in both of the experiments and line graphs were drawned to define the relation between Planck constant and distance between light source and target. This relation allowed us to comment on relation between stopping potential and distance between light source and target metal. The results of the experiment supported the hypothesis “If the distance between the light source and target metal is increased, the stopping potential applied for the photoelectrons decreases.”As a conclusion the variables such as distance intensity of light, air condition have slightly affects on stopping potential, that’s why the literature formula does not consist of these factors.

Word Count:293

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Introduction

Background Information:

Light, as it has been surveyed throughout a long and furious process of investigation, is a substance like no other. The origin of light itself, is specificly not possible to define and describe. The essence of its properties cannot be simply defined by such conventional concepts as wave or particle. Some suggest the light is neighter, while some say it is both. The first significant attempt to explain the fundament of this phenomenon has been made by Isaac Newton in late 17th Century. His scientific perspective was primarily based on the notion that the universe is set upon rigid and methodical principles. So, he concluded that the light is fundamentally nothing more than a beam of propogating particles , which he named "corpuscles". Yet, even in the dawn this new area of scientific progress, the dispute over the truth behind the nature of light was somewhat acute. Christiaan Huygens, for one instance, derived a series of mathematical equation and formulae, suggesting that the light was emitted in all directions as a series of waves in a medium. In the 19th century, Thomas young's "Double Slit Experiment" confirms the diffraction of light and made an evidence for the light behaves as waves. After his investigation, Augustin Fresnel supported Young's experiment with mathematical calculations. On the other hand, another different theory came from Max Planck in 1900 , that the light constist of finite package of energy ,"quanta" , that depends on the velocity and wavelength of the radiation. After 5 years, Albert Einstein put forward another idea to solve the dilemma, as the light has both wave and particle characteristics. So the idea of photoelectric effect can be explained by both the feature of light characteristics(1).

Photoelectric effect was first investigated in 1887 by Heinric Hertz. Investigation occurred while Hertz making an experiment on electromagnetic waves, the electric arcs which were created in the air gap between anode and cathode created when ultraviolet light sent to the cathode part. After a period of understanding the situation, physicist conclude as "Electrons radiates from cathode when the frequency of light that send to cathode is enough to extract electrons from metal."

The hypothesis named as Photoelectric Effect and the electrons extract from metal by light are named "Photoelectrons".

Electromagnetic wave theory demonstrate the circumstance , by accepting the light is made up both electric and magnetic fields. The light waves oscillate in the direction transverse the direction of wave travel. So, if the light is only have wave characteristics there would not be enough energy to extract electrons to free them from the surface of solid. Therefore, the light seemed to have an position vector but still oscilliating in the same way.

In 1902, Philip E. A Lenard made experiments to understand the situation how the extracted photoelectrons energy depends on the intensity of light. To do so, he used a carbon arc lamp that can set up into different light intensities and lighten a metal solid surface. Additionally, he used a second metal plate to keep the electrons and bound it to the cathode part of circuit system. It made the kepeer plate charged negatively and a thrust between photoelectrons and the collector plate. So it means not all the electrons can reach collector plate unless they do not have enoguh kinetic energy . In addition, if the voltage occuring from battery in the system is increased , the photoelectrons cannot reach the plate after one point of voltage. And, that voltage must be equal to the maximum kinetic energy of photoelectrons.

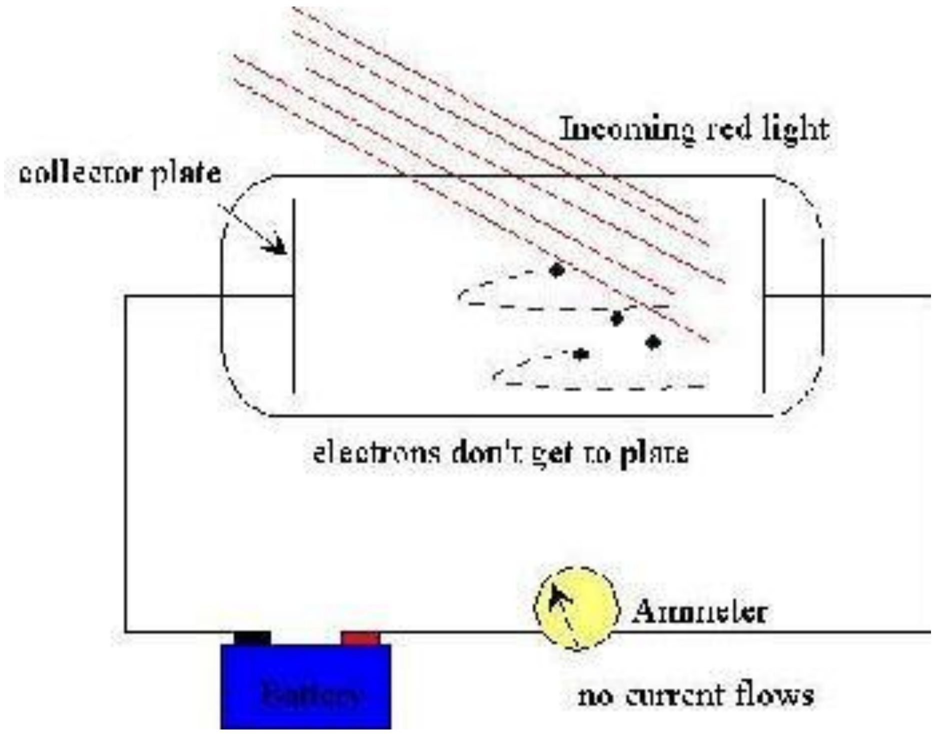


Figure 1.a: The experimental set up of Lenard's photoelectric effect experiment.[2]

The results of Lenard experiment show that the stopping potential (Voltage to prevent photoelectrons to reach collector plate) does not depend on the intensity of light. The situation can not be explained with the electromagnetic theory, and another problem occured when the different wavelength of lights used as independent variable. Because kinetic energy of the photoelectrons increased when the frequency of light increased (1).

The inexplicable results was explained in a different way of thinking, that the energy of light kept in small energy packages by Albert Einstein who assumes the light is made up from quantums that have "velocity multplied by Planck constant " amount of energy. Moreover, the energy of a photon is depend on its frequency. With this idea, the results of Lenard's experiment can be explainable and it is still common in physics. Despite the fact that Rober Andrews Milikan was trying to contradict the assumption of Albert Einstein –due to the assumption is against to the classic electromagnetic wave theory-, the only result that he gained from his experiment was some proves for the Einsteins theory and a close value for

Planck's constant based on formula for energy of photons. (E = h . v)[8]

The results of Lenard and Milikan’s experiment about photoelectric effect can be explained by Einstein’s assumption. If we assume a photons energy as h.v (Planck constant multiplied by frequency of light), it should be absorbed by electrons on the metal plate and increase their kinetic energy for “h.v”. However, the electrons can not extract immediately because of the potential energy that binds them to the metal surface. So that, there should be enough energy to exceed a “threshold level” of energy to extract electrons from the surface.

To present in mathmatical formulas:

$E = h . v$

E = Energy of one photon (Joule or Electron-volt)

h = Planck constant (apx. $6.63x10^{-34}$ j.s)[3]

v= Frequency of light (Hz)

Kinetic energy pf photoelectrons is equal to energy of photons subtracted from potential energy between electrons and metal plate.

$KE = h . v - W$

KE = Kinetic Energy

h.v = Energy of photon (Joule or Electron-volt)

W = Work function (The least required energy to extract electrons from metal surface, can be differ depend on type of metal.) (Joule or Electron-volt)

$V_0 = W/ h$

V_0 = Stopping Potential (e.V)

W = Work function (varies on type of metal)

h = Planck Constant (apx. 6.63×10^{-34} j.s)[3]

In conclusion, there are three results that observed from the experiment and calculations:

*the frequency of the light needed to reach a particular minimum value (depending on the metal) for photoelectrons to start escaping the metal[1]

*the maximum kinetic energy of the photoelectrons depended on the frequency of the light[1]

*the potential energy that prevents extraction of electrons from metal surface is depend on type of metal plate

Research Question:

In a photoelectric system , what is the effect of distance between tungsten lamp and the metal photoelectric module on the stopping potential of system and how does the effect vary with changing wavelength of light?

Explanation: Theoritically, the distance between metal plate and light that is sent through the metal surface has no effect in work function of metal and stopping potential in mathematical equations (9). In these case, many of photoelectric experiments consists of variables in the equation. In other words, I made an experimental assumption, “If the distance between the light source and target metal is increased, the stopping potential applied for the photoelectrons decreases.” to check the formula based on photoelectric theory. Not at all, to identify the uncertainty value precisely, I have done another experiment to define the Planck constant with the same metal plate, light and 5 color filters different from each other. The difference between literature value and the experimental value of the Planck constant gives us the systematic uncertainty of the experiment.

Hypothesis:

If the distance between the light source and target metal is increased, the stopping potential applied for the photoelectrons decreases for all wavelength of light.

Experimental Set-Up:

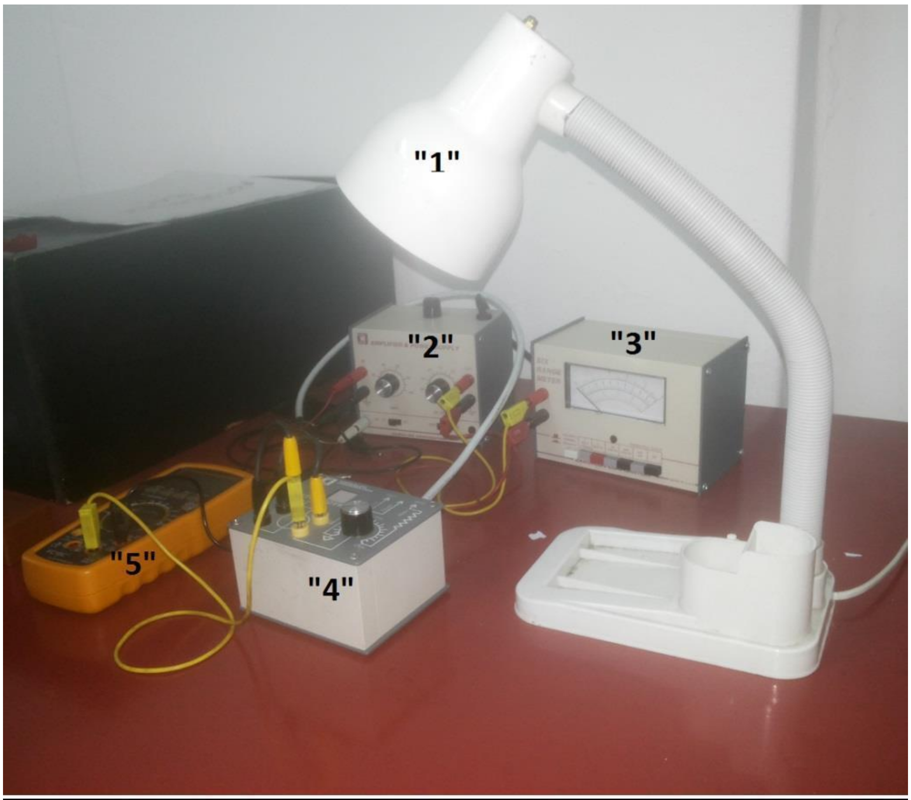


Figure 1.e: The equipment used in the experiment.

The materials used in both preperformance for the uncertainty calculation and the experiment are listed below:

1. Lamp (with tungsten wick)

2. Positive booster - Power Source (To increase the voltage in the system.)

3. Voltmeter (±2,5%V)

4. Photoelectric effect module

5. Multimeter (±0.8**%** +1V**)**

6. 5 different color filter

(Size: 4 cm^2 square. Wavelengths for filter A, B ,C , D ,E ; 430, 490, 508,530,600 nm respectively.)

Note: Wavelentgh of the filters depends on their colors.

7. 1 meter stick (±0.5 cm)

8. Protractor (±1˚)

9. 50 cm^2 ,square cubbard

<u>Variables in Error Calculation Experiment:</u>

Independent Variable: The wavelength of light sent on to photocell. This parameter will be changed by using color filters.

Dependent Variable: The stopping potential ofthe photocell. It is the minimum voltage that should be applied across the plates to stop electron passage.

Controlled Variables:

1) Work Function.(The work function is constant due to the usage of same photoelectric effect module.) (It differs by the type of metal and can effect the Planck constant found in experiment.)

2) Intensity of light (lux, intensity of light just affects the number of photoelectrons excited from metal plate , but it is better to keep constant by using just one point source of light with constant intensity.)

3) Area of target material (if the area changes, amount of light absorbed by photoelectric effect module changes and so the intensity of light differs.) (the area of target material is constant due to the usage of same photoeletric effect module in the experiment.)

4) Temperature, humidity, quality of air (These factors slightly have an effect on the measurements , but they can be measured by “Indoor quality meters”.)

Variables in “*Performance Experiment*”:

Independent Variable: Distance between light source & photoelectric effect odüle. (This parameter was changed by measuring with meter stick)

Dependent Variable: The stopping potential ofthe photocell. It is the minimum voltage that should be applied across the plates to stop electron passage.

Controlled Variables:

1) Wavelength of color filters (The wavelength of color filters directly affect the Planck constant found in the system, so the color of filter was controlled before every data taken.)

2) Angle of incidence of light (Degree. Since the point source is used in the experiment small deflections at the edges of target metal may occur. However, very small surface area of target makes this angle very smalle to regard.)

3) Work function of metal. (The work function is constant due to the usage of same photoelectric effect module.) (It differs by the type of metal and can effect the Planck constant found in experiment.)

4) Intensity of light (lux, intensity of light just affects the number of photoelectrons excited from metal plate , but it is better to keep constant by using just one point source of light with constant intensity.)

5) Area of target material (if the area changes, amount of light absorbed by photoelectric effect module changes and so the intensity of light differs.) (the area of target material is constant due to the usage of same photoeletric effect module in the experiment.)

6) Temperature, humidity, quality of air (These factors slightly have an effect on the measurements , but they can be measured by “Indoor quality meters”.)

Note: There are still 5 Color filter used for evaulating the effect of distance in case if there is a difference in effectiveness of distance between light source and photoelectric effect module. depend on the different frequencies.

Method for Uncertainty Calculation:

The system was setted as shown in Figure 1.b . The distance between light and photoelectric efffect module was measured by meter stick and the value was noted to Table 1.a. Positive booster-power source was turned and the button with a sign of “DC-AC” was turned it to DC. The button “1 Volt” (100γA) on the multimeter was pressed. The hole that absorbs light was closed by the square cubbard. “DC OFFSET” was turned slightly until the value on the multimeter became “0”. The cubbord was carried away and “Filter A” was put on the hole in the Photoelectric Module. Light source was turned on and the “Resistance control” button on the multimeter was turned until the value on the multimeter becomes “0”. The value was written down. The steps was repeated for another 4 times. The “Filter A” was changed to “Filter B” and the experiment was repeated for 5 times. The steps was repeated with using Filter C, D and E.

Note: After every data taken, the hole that absorbs light was closed by the square cubbard. “DC OFFSET” was turned slightly until the value on the multimeter became “0”. It was necessary to reset the value on the multimeter before another data taken.

Figure 1.b: The experimental set up for “The uncertanity calculation ” & “Performance ”

Method for "Performance Experiment"

The system was setted as shown in Figure 1.b . Positive booster-power source was turned and the button with a sign of "DC-AC" was turned it to DC. The button "1 Volt" (100γA) on the multimeter was pressed. The hole that absorbs light was closed by the square cubbard. The button "1 Volt" (100γA) on the multimeter was pressed. . The hole that absorbs light was closed by the square cubbard. "DC OFFSET" was turned slightly until the value on the multimeter became "0". The meter stick was used to set the the distance between light source and photoelectric effect module to 10 cm height. The cubbord was carried away and "Filter A" was put on the hole in the Photoelectric Module. Light source was turned on and the "Resistance control" button on the multimeter was turned until the value on the multimeter becomes "0". The value was written down.The steps was repeated for 4 times. Then the meter stick was used to set the the distance between light source and photoelectric effect module to 20, 30, 40 and 50 cm for the same measurements with different distances . The "Filter A" was changed to "Filter B" and the experiment was repeated for 5 times. The steps was repeated with using Filter C, D and E.

Note: There are still 5 Color filter used for evaulating the effect of distance in case if there is a difference in effectiveness of distance between light source and photoelectric effect module. depend on the different frequencies.

Data Collection & Processing:

Preperformance for uncertainty calculation:

Filters	Blue 1 Filter Paper (430nm ±1nm)	Orange Filter Paper (490nm±1nm)	Yellow Filter Paper (508nm ±1nm)	Green 1 Filter Paper (530nm ±1nm)	Red 1 Filter Paper (600nm ±1nm)
Trials	"Filter A"	"Filter B"	"Filter C"	"Filter D"	"Filter E"
1	0,997	0,823	0,812	0,768	0,530
2	0,932	0,831	0,821	0,800	0,592
3	1,033	0,819	0,814	0,847	0,571
4	0,990	0,799	0,807	0,805	0,553
5	1,007	0,827	0,792	0,763	0,590
Avarage Stopping Potential (±,0,001)	0,992	0,820	0,810	0,797	0,567

Table 1.a: The raw data table shows all the obtained data from the experiment, including stopping potentials for each filter papers and for 5 trials in a specific constant distance. The distance is determined as 10.01 ± 0.01 cm and the work function of metal equals 4.14 eV.

Note:

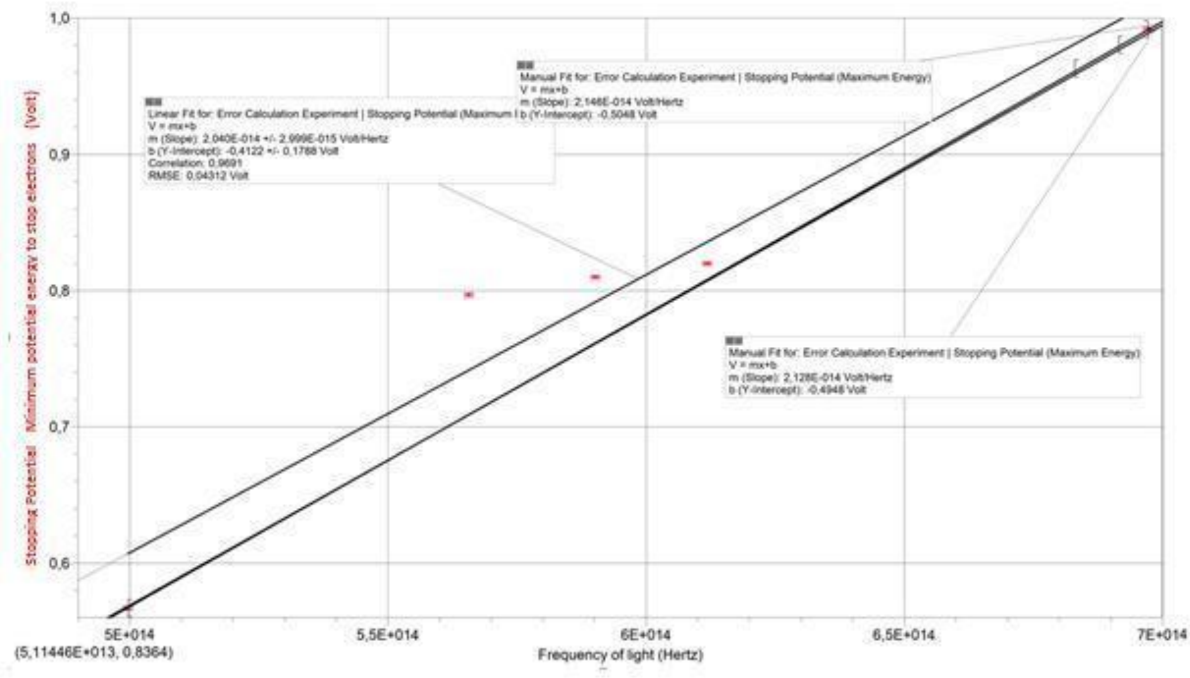
To calculate the Planck constant from these data, we can use Frequency versus Stopping Potential graph which we can define Planck constant, work constant and thershold level.

First we need to calculate frequency of light that can pass through the filters and arrive photocell. To do so, we use (c= λ.f)[4] equation where c is speed of light (apx. 3.10^{8} m/s), γ is wavelength of light (in nanometers) and f is frequency ol light (hertz) .

The calculated frequencies are presented below;

Wavelength (10^{-9} m)	Frequency ($.10^{8}$)
430	499654
490	565646
508	590143
530	611821
600	697192

Table 1.b: The table shows frequency of light that can pass through the filters and arrive photocell.



Graph 1.1:

This linear graph shows the stopping potential varying with frequency falling on photocell.

Data Analysis of Uncertainty Calculation Experiment:

Planck Constant:

Planck costant can be defined as the slope of graph due to the equation :

hf = Φ + KEmax [5]
H= Planck constant (eV.s)

Φ= Threshold level (joule)

f=frequency (hertz)

KEmax=Maximum kinetic energy of emitted electron (joule)

So, Planck constant obtained from the experiment is equal to **$2{,}04.10^{-15} \pm 1{,}00.10^{-16}$ eV.s**

Threshold Frequency:

Threshold frequency is equal to the point of line on x axis, which is **$2{,}01.10^{14}$ Hz.**

The percentage error for Planck Constant:

Literature value: $4.135667516\times10^{-15}$ eV.s [6]

Experimental value: $2{,}04.10^{-15}$ eV.s

Percentage Error: $[(4.135667516\times10^{-15} - 2{,}04\text{x}10^{-15}) / 4.135667516\times10^{-15}]$ x 100 =50.67
“50.67%”

Performance Experiment:

Distance btw. Lamp & filter paper (±0,01 cm)	Trials	Stopping Potential of Blue Filter Paper (A) (430nm) (Joule.coulomb^{-1}) (±0,001)	Stopping potential of Light Blue Filter Paper (B) (490nm) (Joule.coulomb^{-1}) (±0,001)	Stopping potential of Light Blue 2 Filter Paper (C) (508nm) (Joule.coulomb^{-1}) (±0,001)	Stopping potential of Green D) Filter Paper (530nm) (Joule.coulomb^{-1}) (±0,001)	Stopping Potential of Yellow Filter Paper (600nm) (E) (Joule.coulomb^{-1}) (±0,001)
10,01	Trial 1	0,997	0,823	0,812	0,768	0,530
10,01	Trial 2	0,932	0,831	0,821	0,800	0,592
10,01	Trial 3	1,033	0,819	0,814	0,847	0,571
10,01	Trial 4	0,990	0,799	0,807	0,805	0,553
10,01	Trial 5	1,007	0,827	0,792	0,763	0,590
	Avarage Stopping Potential	0,992	0,820	0,810	0,797	0,567
20,01	Trial 6	1,035	0,816	0,801	0,818	0,591
20,01	Trial 7	1,023	0,822	0,826	0,774	0,555
20,01	Trial 8	1,002	0,820	0,813	0,779	0,580
20,01	Trial 9	1,050	0,797	0,794	0,817	0,596
20,01	Trial 10	0,996	0,825	0,808	0,757	0,577
	Avarage Stopping Potential	1,021	0,816	0,808	0,789	0,580
30,03	Trial 11	1,044	0,798	0,806	0,806	0,571
30,03	Trial 12	1,039	0,817	0,809	0,815	0,593
30,03	Trial 13	1,009	0,823	0,816	0,804	0,571
30,03	Trial 14	1,077	0,741	0,799	0,819	0,596
30,03	Trial 15	1,074	0,813	0,817	0,818	0,597
	Avarage Stopping Potential	1,049	0,798	0,809	0,812	0,586
40,02	Trial 16	1,057	0,756	0,782	0,809	0,552
40,02	Trial 17	1,094	0,779	0,784	0,813	0,562
40,02	Trial 18	0,999	0,762	0,811	0,802	0,579
40,02	Trial 19	0,987	0,830	0,823	0,815	0,587
40,02	Trial 20	0,984	0,754	0,809	0,802	0,576
	Average Stopping Potential	1,024	0,776	0,802	0,808	0,571
50,01	Trial 21	0,990	0,823	0,798	0,816	0,598
50,01	Trial 22	1,029	0,818	0,812	0,790	0,556
50,01	Trial 23	0,975	0,744	0,786	0,794	0,584
50,01	Trial 24	1,004	0,763	0,793	0,813	0,563
50,01	Trial 25	1,074	0,801	0,801	0,802	0,567
	Avarage Stopping Potential	1,014	0,790	0,798	0,803	0,574

Table 2.A:

This raw data table shows the the stopping potentials for 5 filters depend on 5 different distance between lamp and photoelectric module with their uncertainties.

Note: Error Calculation experiment data is shown as trial 1 to 5 . (It can be used due to keeping the materials same for the experiments.)

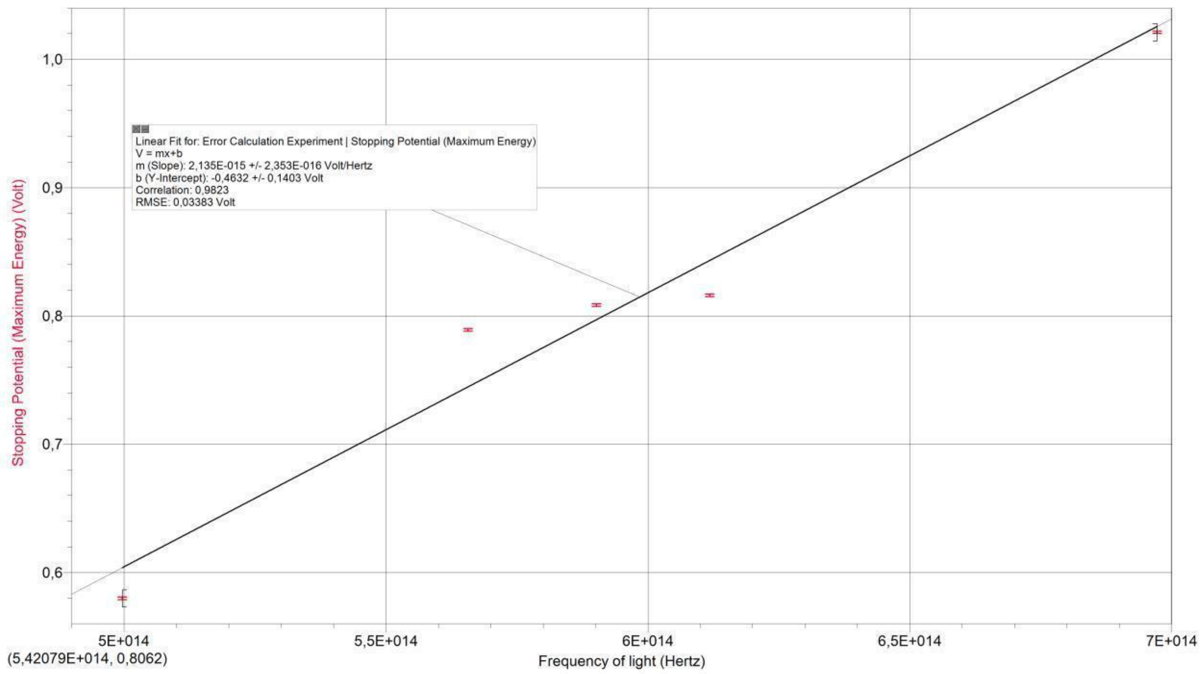
For Distance between source and photoelectric module as "10,00cm":

Graph 1.1 can be used to define the Planck's constant due to it is done with distance value as "10,01" cm

Planck constant for Graph 1.1 :

$2{,}04.10^{-15} \pm 3{,}0.10^{-16}$ eV

For Distance between source and photoelectric module as "20,01cm":

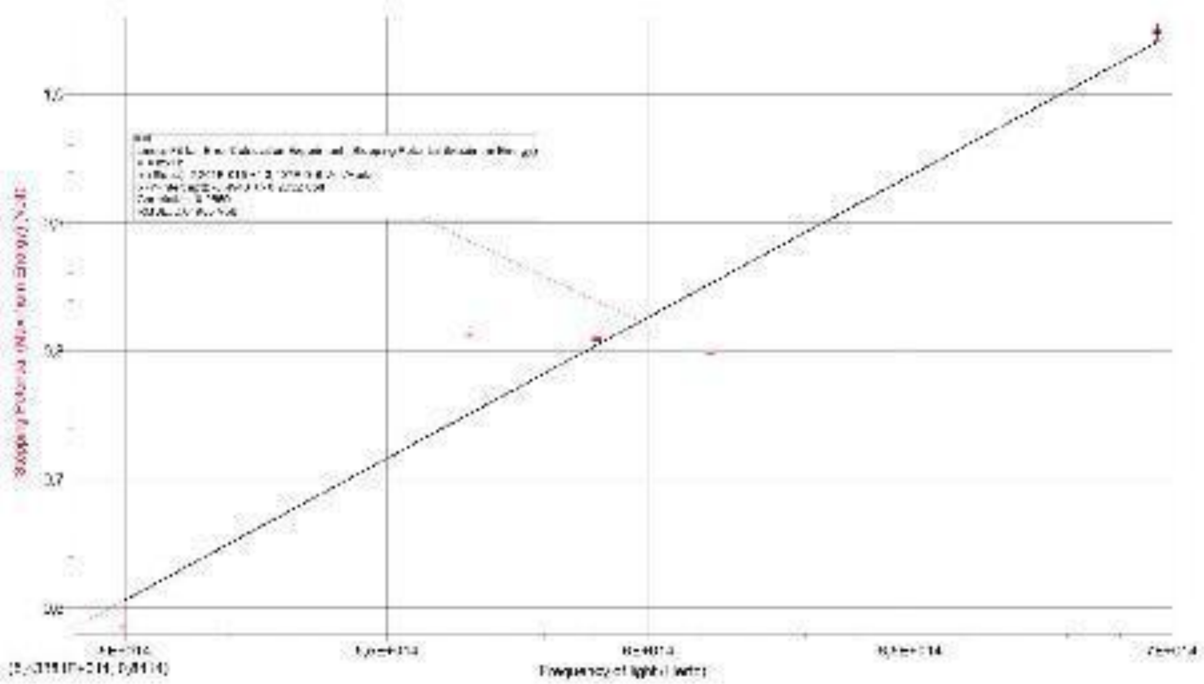


Graph 2.1:

The graph shows change in stopping potential when frequency of light changes with uncertainties for distance as "20.01cm"

Planck constant: **$2{,}135.10^{-15} \pm 2{,}353.10^{-16}$ eV.s**

For Distance between source and photoelectric module as “30,03cm”:

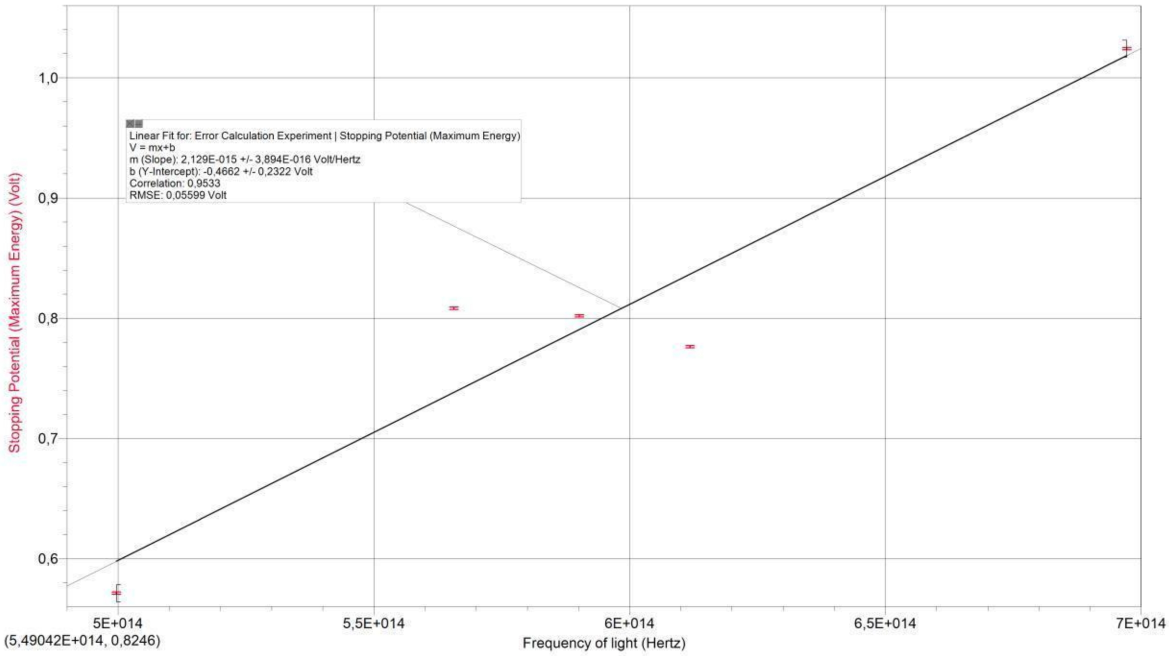


Graph 2.2:

The graph shows change in stopping potential when frequency of light changes with uncertainties for distance as “30.03cm”

Planck constant: **2,201.10^{-15} ± 3,407.10^{-16} eV.s**

For Distance between source and photoelectric module as “40,02 cm”:

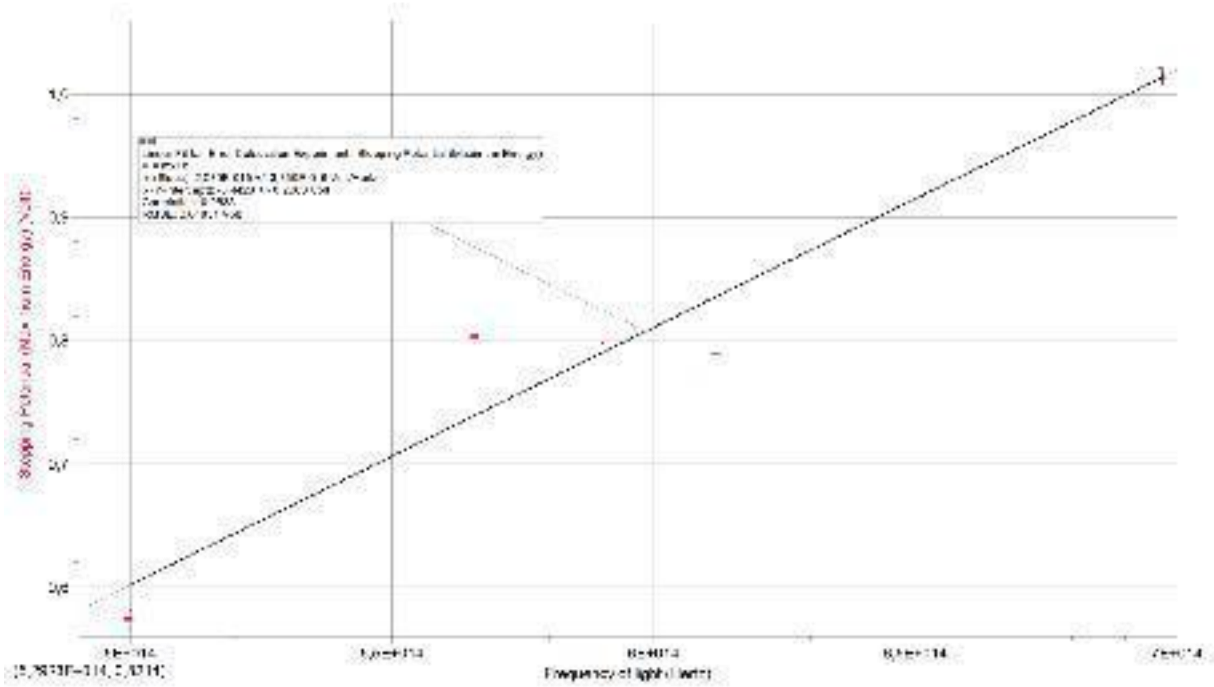


Graph 2.3:

The graph shows change in stopping potential when frequency of light changes with uncertainties for distance as “40.02cm”

Planck constant: $\mathbf{2{,}129.10^{-15} \pm 3{,}894.10^{-16}}$ **eV.s**

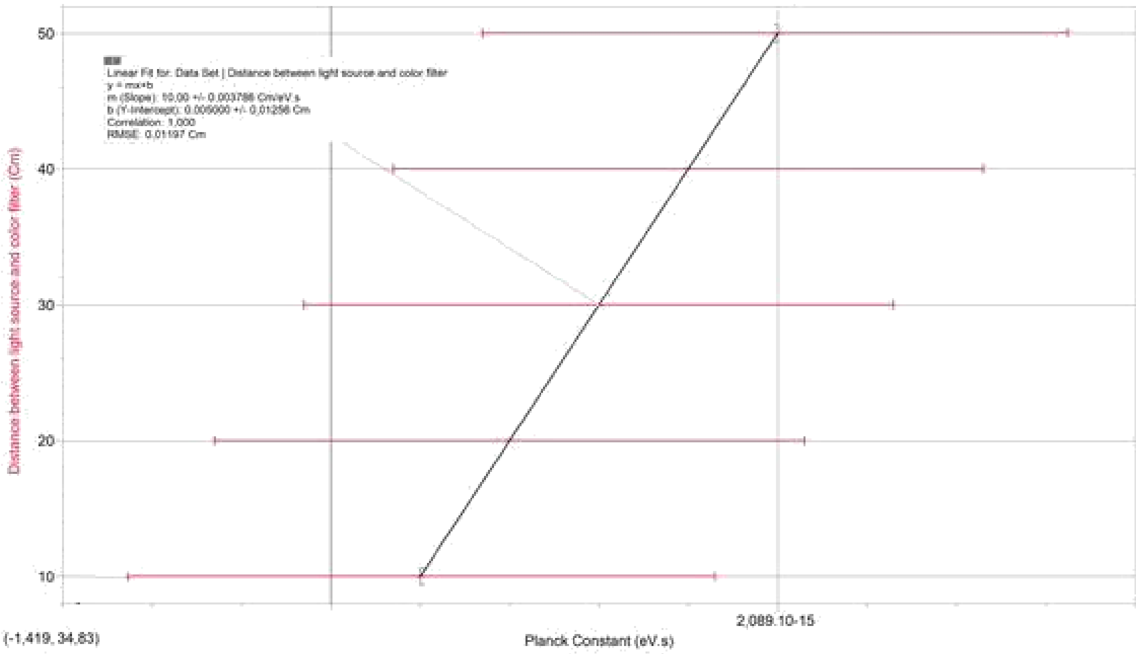
For Distance between source and photoelectric module as “50,01 cm”:



Graph 2.4:

The graph shows change in stopping potential when frequency of light changes with uncertainties for distance as “40.02cm”

Planck constant: **2,089.10^{-15} ± 3,359.10^{-16} eV.s**



Graph 3.1: The line graph shows the change in Planck constant in 5 different distances with their unique uncertainities.

Data Analysis:

Graph 1.1: The graph shows 5 different values of stopping potential in different frequences with uncertainities. First, the stopping potential is approximately 0,570 eV in 5.10^{14} hz. Then, an incerease occcurs with a high slope between two, cause apx. 0,220 eV increase from the first one in $5,5.10^{14}$ Hz. But in two other continuous data, the slope of the line sharply decreases and there is just apx. 0,02 eV increase occurs in each of value. On the other hand, the final frequency, 7.10^{14} cause an increase about 0,160 eV and affect the slope of the line as well.

Graph 2.1: The graph shows 5 different values of stopping potential in different frequences with uncertainities. In addition, it is drawn as a result of main experiment, with 20,01 cm displacement between light source and photoelectric effect module. There is a great increase same like graph 1.1 and the slope of connections between data is higher for first and last data.

Graph 2.2: The graph shows 5 different values of stopping potential in different frequences with uncertainities. In addition, it is drawn as a result of main experiment, with 30,03 cm displacement between light source and photoelectric effect module. It is very similar with Graph 1.1 and 2.1 but there is a noticable between third and fourth value. The stopping potential decreased by apx. 0,01 while the frequency increased. On the other hand, in general the stopping potential is proportional to frequency of light.

Graph 2.3: The graph shows 5 different values of stopping potential in different frequences with uncertainities. In addition, it is drawn as a result of main experiment, with 40,02 cm displacement between light source and photoelectric effect module. In overview, it seems like stopping potential increases when the frequency of light increase but between second and fourth value, reduction occurs and it affects slope of the line in a decreasing way.

Graph 2.4: The graph shows 5 different values of stopping potential in different frequences with uncertainities. In addition, it is drawn as a result of main experiment, with 50,01 cm displacement between light source and photoelectric effect module. The graph is similar with graph 2.2 and 2.3 and there is no other noticable difference between them.

Graph 3.1: The graph shows Planck Costant and distance between light source and photoelectric module is proportional in same phase. But , as a side effect of using avarage values of data to find Planck's constant, uncertainity of Planck's constant is not same with each other and wider than the expected uncertainty as shown in page 10.

Conclusion & Evaluation:

The aim of the experiment is defining the effect of distance between light source and photoelectric module on the stopping potential of system and using five different color filters to calculate the Planck constant found in system. The investigation starts with a pre experimentation to calculate percentage uncertainty between experimental and literature value of Planck constant when the distance between light source and photoelectric effect module was kept as "10" cm. Then, the experiment was done for 4 other distances (20,30,40,50 cm) and based the error calculation experiment data as literature to comment about the effect of distance. The Graph 3.1 shows there is an increase in Planck constant when the distance is increased. In addition, to comment the relation between Planck constant and stopping potential, the work function was kept same by not changing the photoelectric effect module and light source and made Planck constant as a dependent variable that can change in every single experiment.

To achieve a conclusion, the Graph 3.1 was used. Planck constant and the distance between light source and target metal are directly proportional. The relation between Planck constant and stopping potential can be commented by the formula "$V_o=W/h$" [10]. Because, the work function of metal is constant so the stopping potential is inversely proportional to Planck constant. So, the result of the experiment shows that distance between the light source and target metal increases the stopping potential found by the system decreases. By the way, the result supports my hypothesis "If the distance between the light source and target metal is increased, the stopping potential applied for the photoelectrons decreases.".

To calculate the system error precisely, I made a preperformance and calculated the percentage error as **“50.67%” .** As a result of experiment, It allow us to discuss about the confidence of the system. There can be approximately 50% difference in Planck constant (and stopping potential) caused by systematic error.

The reasons behind the noticable percentage error are error sources and limitations in the experiment. First of all, the material (meter stick) used for evaulating the distance between light source & photoelectric effect module had a 0.1 cm uncertainty value, which slightly affects the distance. Also, the photoelectric effect module that absorbed light had a percentage error, which directly affects the stopping potential and cause a wide range of uncertainty on “Graph 3.1”. Another limitation might be that the intensity of light that can not precisely controlled. The reason is, the point light source can not directly send the light with same intensity to the photoelectric efect module in different distances due to the wave characteristic of light, which cause a decrease of intensity when distance increases. In addition, the sunlight reached the system could cause a difference in intensity of light Not at all, the experiments about photoelectric systems are done in vacummed areas to calculate a precise value. So, the air particles might have some effect on stopping potential. .

However, in literature, none of these factors (7) except work function of metal have an effect on stopping potential. The stopping potential is only effected by work function and the distance between light source and photoelectric effect module creates no change in stopping potential value. Despite the fact that the result of the experiment and literature are not same, there is one thing can be commented. In theoritical formulas, there could be some variables which are have lower effect than the other variables so can be neglected to make simple calculations.

To sum up, the result of the experiment shows the stopping potential decreases when the distance between the light source and target material increases.

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